<u>Amendments to the Specification:</u> This Specification will replace all prior versions of Specifications in the application.

<u>Revised Description of the Specification</u>

(Original) CROSS REFERENCE TO RELATED APPLICATION

(Original) [0001] This application claims benefit of U. S. Patent Provisional application Serial No. 60/431,004 filed Dec. 5, 2002. Subject matter set forth in Provisional application serial No. 60/431,004 is hereby incorporated by reference into the present application as if fully set forth herein.

(Original) BACKGROUND OF THE INVENTION

(Currently Amended) [0002] This invention relates to fuel cells and more specifically to fuel cells that can be manufactured using conventional semiconductor fabrication equipment and facilities. The complete fuel cell structure ~~(including top channeled plate)~~ <u>(including channel cover plate structures)</u> is manufactured sequentially, <u>structure on top of structure,</u> on one side of a planar <u>single</u> monolithic substrate.

(Original) [0003] Fuel cells are devices for converting stored chemical energy directly into electricity generally by using conventional fuels such as hydrogen, methane, methanol and gasoline, for example. The oxidizer commonly used is air or oxygen. The liquid fuels are typically reformed, so called, and hydrogen gas is extracted from the fuel then used by the fuel cell. Hydrogen ions are conducted through a cell membrane to a cathode structure while the ionic properties of the membrane prevent the passage of electrons that have been stripped from the hydrogen gas. Electrons are thus forced to flow through an external load and back to the anode to recombine with the hydrogen ions to form the non-polluting reaction product water. Alternatively hydrogen gas can be used directly with air or oxygen negating the need for a reformer.

(Original) [0004] Fuel cells provide a convenient solution for electrical energy production with lower levels of point of use pollution especially small compact fuel cells that can replace batteries for portable electronic components such as cell phones and notebook computers, for example. End of life disposal of fuel cells is expected to be less polluting than that of batteries.

(Original) [0005] Large stationary fuel cells are in use primarily as backup electrical power where power outages cannot be tolerated. These stationary fuel cells may typically range from 1 KW to in excess of 100KW. Non stationary fuel cells have found application to a limited degree in commercial vehicles such as busses where they use natural gas fuel, however the prevalence of such systems is quite limited.

(Original) [0006] The predominant structure of current fuel cells found in stationary installations is one of component separate parts that are assembled by hand labor. The essential components are a membrane, two electrodes and channeled anode and cathode plates that are assembled together by a variety of means - often simply held in a sandwiched stack by bolting them together. The manufacture and assembly is time consuming and labor intensive. Such an approach to manufacturing extended to small portable fuel cells becomes even more difficult and labor intensive leading to high cost of product.

(Original) [0007] While there is intense current research and development on the materials that go into the manufacture of the core fuel cell focused to improve efficiency and reliability the manufacturing cost per watt hour is much higher than common current methods of power production such as gasoline generators and batteries, for example.

(Currently Amended) [0008] The fuel cell electrode assembly ~~structure~~ described herein is fabricated on a single side of a flat monolithic substrate wherein all the component ~~elements~~ structures of the fuel cell including ~~membrane, electrodes, catalyst, electrical conductors and fuel and oxidizer channels with outlet feed channels to fuel and oxidizer manifolds~~ anode and cathode metallic conductors, anode and cathode electrode

catalyst structures, ion exchange membrane structures, fuel and oxidizer channel structures and fuel and oxidizer manifold supply and exhaust structures are fabricated in a conventional semiconductor fabrication facility. Such fuel cell ~~structure~~ electrode assembly herein described affords the greatest opportunity for manufacturing economy and provides a serious opportunity for the production of fuel cell ~~elements~~ electrode assemblies of centimeter square unit cell sizes that can be singulated and stacked or conversely interconnected as an array on a single substrate. Substrate size may be from 4 to 12 inch diameter for example for convenient manufacture in a conventional semiconductor fabrication facility. The structure is fabricated with fuel and oxidizer manifold supply and exhaust structures ~~cavities~~ at the edge of each unit fuel cell electrode assembly enabling the stacking of unit cells or entire substrates for increasing voltage or current output from a stack.

(Original) [0009] U.S. Patent 4,294,891, to Yao, et al. describes a micro fuel cell that is implantable (in humans) and has a structure that permits refueling through a percutaneous port. Essential components of the fuel cell are fabricated separately then assembled prior to implant.

(Original) [0010] U.S. Patent 5,641,585, to Lessing, et al. discloses a miniature ceramic fuel cell including an elemental cell with balance of plant. A solid oxide fuel cell is disclosed wherein a planar anode of nickel or zirconium oxide, a planar electrolyte of zirconium oxide, a planar cathode of lanthanum manganese oxide and a planar interconnct of nickel/aluminum are manufactured separately then joined by cobalt/nickel brazing.

(Original) [0011] U.S. Patent 5,723, 228, to Okamoto describes a direct methanol type fuel cell wherein the design discloses a method for uniformly delivering a proper amount of fluid methanol to an entire anode surface. The structure of the elemental fuel cell comprises an ion exchange membrane, anode, cathode, anode gasket, cathode gasket, and two manifold plates fabricated separately then assembled in registration.

(Currently Amended) [0012] U.S. Patent 6,127,058, to Pratt, et al. discloses a fuel cell demonstrating an integrated anode, cathode and membrane on a single substrate and where the anode and cathode is applied to opposite sides of the membrane. <u>Separate</u> anode and cathode current collector plates are then attached to the opposite sides of the anode, cathode, membrane assembly.

(Original) [0013] U.S. Patent 6,312,846, to Marsh discloses a miniature fuel cell that is a departure from prior art wherein the active fuel cell components including membrane, electrodes, fuel and oxidizer channels and current conduction paths are built up on a single, channeled, monolithic substrate through sequential depositions of conductive (electrode) and nonconductive (membrane) polymer. Channels are initially formed in the substrate followed by the application of membrane and electrode material and finally a separate gas impermeable cover seals the structure. Also disclosed is an alternative method of manufacture wherein three grooves (membrane, anode and cathode electrode grooves) are etched into the substrate followed by electrical conductor deposition and finally the injection of flowable membrane material into the center groove. The possibility of introducing semiconductor microcontroller devices onto the substrate for the purpose of monitoring various functions of the fuel cell as well as providing sensing and output power control is disclosed.

(Original) [0014] U.S. Patent 6,387,559 B1, to Koripella, et al. describes a fuel cell system consisting of a fluid supply array of channels in a base structure with a membrane assembly including separate proton conducting membrane, anode and cathode attached to the channeled substrate. The channeled substrate acts as a partial balance of plant for the insertion of fuel and oxidizer to the membrane assembly part of the fuel cell.

(Original) [0015] U.S. Patent 6,497,975 B2, to Bostaph, et al. discloses a fuel cell assembly as described in U.S. Patent 6,387,559 above but with the addition of an integrated flow field within an upper and lower plate containing fluid and oxidizer flow

channels where the stated purpose is to supply a uniform distribution of fuel and oxidizer to a membrane surface.

(Currently Amended) [0016] U.S. Patent 6,541,149 B1, to Maynard, et al. discloses a mirco fuel cell wherein fuel and oxidizer channels are formed on two silicon substrates and where a proton exchange membrane is added to one of the substrates then the two substrates are bonded together to form an elemental cell containing membrane, electrodes, catalysts and current collecting members. In another embodiment the elemental cell is formed on a single substrate through sequential buildup of porous membrane, fuel and oxidizer channels, catalyst and electrodes, current carrying conductors and finally a proton exchange membrane. The unique fabrication process provides for ion conduction essentially in the plane of the substrate <u>but with the conducting surface in the plane of the substrate and the necessity for adding a separate top cover plate with imbedded current collector structures.</u>

(Original) [0017] U. S. Patent 6,638,654, to Jankowski, et al. describes a MicroElectroMechanical Systems (MEMS) based fuel cell consisting of three substrates which are bonded together in registration to form a functional micro fuel cell fabricated using principally semiconductor type processing equipment. A porous membrane and electrode/electrolyte layer is provided on a center substrate, which may be silicon or other material, a channeled top substrate with an O2 inlet is provided and finally a bottom substrate with fuel channel and inlet is provided. The three substrates are bonded together to form an elemental fuel cell. Balance of plant equipment is not described.

(Original) [0018] U.S. Patent 6,641,948 B1, to Ohlsen, et al. discloses a fuel cell structure comprising an anode assembly and cathode assembly fabricated separately from micromachined silicon wafers wherein the anode and cathode components are bonded together using a third bonding structure and the flow channels within the anode and cathode members are sealed using flow channel covers. The fuel cell is unique in that the current extraction means is through the micromachined silicon substrates.

(Original) BRIEF SUMMARY OF THE INVENTION

(Currently Amended) [0019] A fuel cell electrode assembly structure is disclosed wherein a fully functional fuel cell device is formed on a single side of a monolithic substrate. The ~~structure~~ electrode assembly includes ~~a substrate, anode and cathode current extractors, electrodes with integral catalyst, Proton Exchange Membrane (PEM), and fully sealed fuel and oxidizer channels~~ the single monolithic substrate, anode and cathode metallic conductor structures, anode and cathode electrode catalyst structures, ion exchange membrane structures, fuel and oxidizer channel structures, channel cover plate structures and fuel and oxidizer manifold supply and exhaust structures. ~~feeding to integral manifolds.~~

(Currently Amended) [0020] The fully integrated fuel cell electrode assembly is fabricated on a single monolithic substrate by sequential additive and subtractive processes commonly used in semiconductor and MEMS fabrication technology.

(Currently Amended) [0021] The objects and advantages obtained by the fuel cell electrode assembly herein ~~element~~ derive from the alternating anode and cathode metallic conductor structures ~~electrodes~~ and fuel and oxidizer channel~~s~~ structures that are ~~structured~~ formed in a single plane. This enables sequential additive and subtractive processing to complete the invention. Such structures ~~is~~ are executed using conventional semiconductor and MEMS microfabrication technology as well as semiconductor packaging technology wherein said technologies are well known in the art.

(Currently Amended) [0022] The ~~structure~~ fuel cell electrode assembly described utilizes a hydrogen ion flow essentially parallel to the substrate surface resulting in advantageous simplification of the fabrication process ~~in~~ such that all of the additive and subtractive processes are planar rather than significantly three dimensional.

(Currently Amended) [0023] The ~~unique~~ planar structure of the fuel cell electrode assembly enables the use of insulator materials to be deposited by conventional techniques such as sputtering, evaporation, and chemical vapor deposition, for example. The use of insulator materials are important for the prevention of corrosion and electrical isolation, for example.

(Currently Amended) [0024] The planarity of the fuel cell electrode assembly ~~structure~~ is important in minimizing the amount of catalyst used during fabrication. The application of catalyst can be implemented by means of vacuum deposition, plating or chemical vapor deposition and thus restricted to the vicinity of the ~~membrane/electrode~~ anode and cathode electrode catalyst/ion exchange membrane interface rather than dispersed throughout the entire anode and cathode electrode structure.

(Currently Amended) [0025] The sequential thin and thick film technology used in fabrication of the fuel cell ~~element~~ electrode assembly along with the design provides a basic structure that takes advantage of fuel cell material improvements and that are evolutionary in nature.

(Currently Amended) [0026] The structure design and fabrication process for the fuel cell electrode assembly herein allows the incorporation of refractory barrier materials within fuel and oxidizer channels as well as anti corrosion layers that can be applied to ~~current extractor~~ anode and cathode metallic conductor lines.

(Currently Amended) [0027] Specifically the entire fuel cell electrode assembly ~~structure~~ is fabricated using conventional semiconductor technology with its' attendant high resolution lithography and high yield for mature processes. Such fabrication capability allows a very wide window of dimensional control in the anode to cathode width of the ion exchange membrane (few to several hundred micrometers) as well as thickness of the ion exchange membrane (from a few to several hundred micrometers). Robust, low resistance, plated, current carrying anode and cathode metallic conductor structure ~~electrodes~~ lines are enabled using simple plating technology. Uniquely the entire fuel

cell electrode assembly ~~structure~~ is fabricated sequentially on a single side of a planar monolithic substrate.

(Original) BRIEF DESCRIPTION OF THE DRAWINGS

(Original) [0028] FIG. 1a illustrates prior art wherein component members are fabricated separately then assembled together in FIG. 1b

(Original) [0029] FIG. 2 details in an oblique, cutaway view of the salient features and structure of the present embodiment of the invention.

(Currently Amended) [0030] FIG. 3 details a schematic diagram of ~~a~~ the fuel cell electrode assembly ~~element~~ of the present invention.

(Currently Amended) [0031] FIG. 4a through 4g illustrates a preferred embodiment of a fabrication sequence from starting single monolithic substrate through current extractor ~~electrode~~ anode and cathode metallic conductor structure fabrication.

(Currently Amended) [0032] FIG. 5a through 5e indicates a continuation of a preferred embodiment of the fabrication sequence from ~~current extractor~~ anode and cathode metallic conductor structure barrier metal deposition to ~~proton~~ ion exchange membrane deposition.

(Currently Amended) [0033] FIG. 6a through 6e delineates a continuation of the preferred embodiment of the fabrication process from ~~proton~~ ion exchange membrane structure deposition through catalyst application to the ~~proton~~ ion exchange membrane structures.

(Currently Amended) [0034] FIG. 7a through 7d illustrates a continuation of the preferred embodiment of the fabrication process from the deposition of the ~~fuel cell~~ anode and cathode electrode catalyst structures material through the resist mask for

forming the fuel and oxidizer channels for the bottom part of the channel cover plate structures.

(Currently Amended) [0035] FIG. 8a through 8c illustrates a continuation of the preferred embodiment of the fabrication process from fuel and oxidizer channel wall plateup of the bottom part of the channel cover plate structures to the fuel and oxidizer channel wall mask removal of the bottom part of the channel cover plate structures.

(Currently Amended) [0036] FIG. 9a shows a top down view of a much reduced in complexity (for the purposes of illustration) fuel cell electrode assembly ~~element~~ indicating the fuel and oxidizer flow channels formed by the channel cover plate structures ~~in the base cell~~ along with (superimposed) the via holes at the end of the channels feeding into channels (bold lines) in the ~~integral~~ channel cover plate structures. ~~cover.~~ Square fuel and oxidizer manifold supply and exhaust structure holes are delineated at the corners of the view which enable stacking of the cells and commutation of fuel or oxidizer source to each of the cells when stacked. ~~stacked cells.~~

Currently Amended) [0037] FIG. 9b and 9c illustrate preferred embodiment of the fuel and oxidizer flow paths through the three layer integrally fabricated channel cover plate structure to the fuel and oxidizer manifold supply and exhaust structure chamber at the edge of the cell. 9b and 9c are derived from sectioning of 9a as indicated in 9a.

(Currently Amended) [0038] FIG. 10a through 10e illustrates in ~~a~~ the preferred embodiment a continuation of the fabrication process performed on the ~~base cell~~ lower part fuel cell electrode assembly previously processed as illustrated in FIG. 4 through FIG.8. FIG. 10a illustrates a first masking layer, followed by lithographic patterning, adhesion and preplate layer deposition, a second masking layer with lithographic patterning and finally a selective cover metal plateup as part of the channel cover plate structure in FIG. 10e.

(Currently Amended) [0039] FIG. 11a through 11d illustrates in a preferred embodiment of a continuation of the channel cover plate structure fabrication process from the ~~first~~ bottom channel cover plate structure ~~cover~~ plateup layer through the application of a second masking and patterning layer to a second adhesion and preplate layer deposition for the top part of the channel cover plate structure.

(Currently Amended) [0040] FIG. 12a through 12c illustrates in a preferred embodiment a continuation of the channel cover plate structure fabrication process from the application and patterning of a third masking layer through the plateup of the second metal ~~cover~~ layer for the channel cover plate structure.

(Currently Amended) [0041] FIG. 13a through 13c illustrates in a preferred embodiment a further continuation of the channel cover plate structure ~~cover~~ fabrication process from application of a second metal ~~layer 2~~ through the removal of all masking material from internal channels. This completes the fabrication sequence for the complete fuel cell electrode assembly.

(Currently Amended) [0042] FIG. 14a illustrates the stacking strategy for assembling multiple fuel cell electrode assemblies ~~elements~~ for the purpose of increasing power density. A cutaway view illustrates the fuel and oxidizer flow paths from large fuel and oxidizer manifold supply and exhaust structure feed passages through the fuel cell electrode assembly channels thence through vias in the channel cover plate structure and along channels in the channel cover plate structure thence back to the exhaust manifold.

(Currently Amended) [0043] FIG. 14b illustrates in a preferred embodiment the strategy for bringing out electrical power to the edge of a stack of cells by exposing an end section of the current carrying anode and cathode metallic conductor feed lines. The figure is shown at 90 degree X - Y plane rotation from the FIG. 14a above.

(Original) DETAILED DESCRIPTION OF THE INVENTION

(Currently Amended) [0044] A ~~micro~~ fuel cell electrode assembly structure and process is disclosed that enables a low cost of manufacture benefit. Although the following detailed description delineates many specific attributes of the invention and describes specific fabrication procedures and structure details those skilled in the art of microfabrication will realize that many variations and alterations in the fabrication details are possible without departing from the generality of the preferred embodiment of the structure as described.

(Currently Amended) [0045] The most general attributes of the invention relate to a fuel cell electrode assembly structure that is fabricated wholly on a single monolithic substrate wherein all of the salient fuel cell electrode assembly components are sequentially built up using conventional semiconductor or MEMS processing techniques. Ion conduction takes place in a plane ~~predominantly~~ parallel to the single monolithic substrate. The invention provides for a reduced manufacturing cost benefit derived from the ability to fabricate the entire structure through sequential processing in a semiconductor or MEMS type fabrication facility. A ~~channeled~~ top channel cover plate structure is fabricated sequentially and on top of ~~with~~ the ~~basic~~ lower portion of the basic fuel cell electrode assembly section ~~cell~~ to provide channels and interlayer vias for the removal of fuel and oxidizer. Fuel and oxidizer manifold supply and exhaust structure channels are opened by masking and etching from the back or front side of the single monolithic substrate at the end of the process. Arrays of fully functional ~~micro~~ fuel ~~cells~~ cell electrode assemblies are fabricated on a single monolithic substrate then singulated for use in small stacked arrays.

(Currently Amended) [0046] Fuel and oxidizer manifold~~s~~ supply and exhaust structures are ~~partially~~ fabricated concurrently with each fuel cell electrode assembly layer ~~at the same time~~ along the edge of unit fuel cell~~s~~ electrode assemblies in order that as fuel cell~~s~~ electrode assemblies are stacked, edge fuel and oxidizer manifold supply and exhaust structure channels are automatically aligned and connected up through the stack and available at the top of the stack for connection to an external source of fuel and oxidizer from balance of plant hardware via an attached tubulation. The completed

~~micro~~ fuel cell~~s~~ electrode assemblies can be stacked by soldering or polymer bonding or other means known in sealing art for example, to achieve higher output current or voltage.

(Currently Amended) [0047] Optionally entire substrates of interconnected individual fuel cell~~s~~ electrode assemblies ~~elements~~ may be stacked to provide a high power fuel cell module. At current state of the art power densities of 0.5 watt per square centimeter an 8 inch diameter substrate containing 150 interconnected cells of 0.5 watts each yield 75 watts. A module of 15 stacked substrates yield 1 KW in a stack volume of 150 cubic centimeters.

(Currently Amended) [0048] The technology in prior fuel cell art has focused on building both macro and micro cells as component parts. To form a functional fuel cell element the component parts are assembled together in a stack generally with some sort of component feature registration required. FIG. 1a shows in simplified form a fuel cell element ~~100~~ consisting of five component parts (balance of plant not included). **110** and **160** are current carrying members fabricated separately and contain channels **120** and **170** while **140** and **150** are electrode members also generally fabricated separately. Membrane **130** is also fabricated separately. These pieces are then bonded together, FIG. 1b, to form a functional fuel cell element, **100**, equivalent to the fuel cell electrode assembly disclosed herein. The assembly process can be expensive and time consuming and does not lend itself to a continuous manufacturing process. Recent interest in micro fuel cell technology for portable electronic applications has resulted in fuel cell designs that are amenable to conventional microfabrication manufacturing techniques. Much of this work has focused on building parts of the fuel cell element separately using conventional microfabrication technology but then assembling the component parts to obtain a fully functional cell. This patent discloses a structure wherein all component parts are integrated within and fabricated sequentially on a single monolithic substrate.

(Currently Amended) [0049] FIG. 2 delineates a cut away view of a preferred embodiment of the disclosed completed ~~monolithic micro~~ fuel cell electrode assembly **200** showing, for simplicity, only the principal components. The fuel cell is built up sequentially using conventional microfabrication techniques on single monolithic substrate **205**. Design of the structure permits fabrication to be executed in a conventional semiconductor fabrication facility that employs thin film deposition equipment, wet and dry etching equipment, plating equipment, lithography equipment, polishing equipment and electrical probing equipment. The fuel cell of FIG. 2 represents a greatly simplified embodiment of an actual cell and the structure represented will be recognized as a functional fuel cell electrode assembly ~~element~~ by those skilled in the art. The fuel cell electrode assembly is fabricated on substrate **205** which can be semiconducting, insulating or metal. The starting substrate is planar and unpatterned in order to be compatible with conventional processing equipment. If the substrate is conducting a first layer (not shown in FIG. 2) of insulator is applied such as silicon nitride, for example. Next a layer of alternating anode **210** and cathode **215** metallic conductor structure current collector lines are built up by masking and plating technique, for example. Next a continuous layer of ~~proton~~ ion exchange membrane **225** is applied to the plated anode and cathode surface. It is photomasked and trenches are etched down to the plated anode and cathode metallic conductor structure current collector lines. Remaining material is heat cured as necessary. Such ~~proton~~ ion exchange membrane material can be applied as a Nafion solution, for example. After trench formation by wet or dry etching technique lines **225** of ~~proton~~ ion exchange membrane are left between the plated anode and cathode metallic conductor ~~current conductor~~ lines. Next a slurry of electrode material containing a catalyst such as Pt or Pt/Rb is applied by spin coating or doctor blading so as to fill the trenches **220** formed in the ~~proton~~ ion exchange membrane material. A masking step is utilized to prevent anode and cathode electrode catalyst ~~electrode~~ material from being deposited in undesirable regions of the monolithic substrate. Anode and cathode electrode catalyst structure material is heat cured as required. Excess anode and cathode electrode catalyst structure material is next removed by mechanical polishing means such that a planarized surface of exposed ~~proton~~ ion exchange membrane and anode and cathode

electrode catalyst structure material result. In order to insulate the metallic fuel and oxidizer channel separators **230** from the ~~proton~~ ion exchange membrane and a portion of the anode and cathode electrode catalyst structures a layer of insulator (not shown in FIG.2) is applied to the planarized surface and preferentially removed over the anode and cathode electrode catalyst structure area by photolithographic patterning. The removal over the anode and cathode electrode catalyst structure area allows for fuel and oxidizer access to the electrode **220** and then laterally through ion exchange membrane **225**. Following selective application of the insulator between **220** and **225** a photomask is applied and used as a plateup mask for fabrication of fuel and oxidizer channel separators **230**. It will be noted that suitable masking steps throughout the process are used to insure that no material is deposited in fuel and oxidizer manifold supply and exhaust structure holes **260**, **265**, **270** and **275**.

(Currently Amended) [0050] Further fabrication steps involving an integral, ~~channeled, cover plate~~ channel cover plate structure can be followed by the aid of FIG. 2. After fabrication of fuel and oxidizer channel separator plates **230** an alternating series of adhesion layer and preplate layer depositions are carried out followed by lithographic masking then plating of the lower channel cover plate structure **240**. Note that ~~plate~~ structure **255** is temporarily supported by lithographically patterned resist, (not shown). ~~Plate~~ Structure **240** contains via holes appropriately placed for removal of fuel and oxidizer from the fuel and oxidizer channels. These channels alternate between oxidizer and fuel or oxygen and hydrogen as indicated, for example. Finally the last solid top ~~plate~~ structure **255** is fabricated using lithographically patterned resist in a process identical to ~~plate~~ structure **240** fabrication. Buildup of ~~plate~~ structure **255** leaves channels **250** between ~~plate~~ structure **240** and **255**. After ~~plate~~ structure **255** fabrication the temporary support resist is removed from buried channels and vias **245** using a hot, circulated compatible solvent. A final step in the fabrication process removes the substrate material at fuel and oxidizer manifold supply and exhaust structure cutout regions **260**, **265**, **270** and **275** by using wet or dry etching technique (depending on the nature of the substrate material) and by masking and patterning the bottom side of the substrate while protecting the previously patterned upper side. Alternatively, and

preferably, the top side of the substrate can be masked and patterned and etching of the fuel and oxidizer manifold supply and exhaust structure cavities accomplished from the top side while protecting the back side of the substrate.

(Currently Amended) [0051] The aforementioned fuel cell electrode assembly ~~element~~ is a completely functional fuel cell (minus balance of plant) fabricated by sequential processing on a single monolithic substrate. Connection to balance of plant is accomplished through attachment of tubulations to fuel and oxidizer manifold supply and exhaust structure cutout regions **260,265**, **270** and **275** by various means such as soldering, epoxy seal, o-ring pressure seal, for example.

(Currently Amended) [0052] A FIG. 3 block diagram illustrates the ~~essence~~ layout of the fuel cell electrode assembly shown in FIG. 2. Fig. 3 presents a simplified layout from top view of a much reduced version of ~~an~~ the ~~actual~~ fuel cell electrode assembly which may contain up to hundreds of flow channels and current extracting electrodes. The fuel cell electrode assembly **300** is built up on single monolithic substrate **305** which is the same as single monolithic substrate **205** in FIG. 2. Fuel, hydrogen, for example, is introduced into supply manifold channel **325** and is distributed through comb structured channels **315** in the lower part of the fuel cell then flows up through vias **340** to an exit channel in the upper cover where it flows into exhaust manifold channel **330**. In a like manner oxidizer, oxygen or air, for example, is introduced into supply manifold channel **320** where it flows into distribution channel **310** and then through comb fingers to vias **345** in the channel cover plate structure then exits at exhaust manifold structure channel **335**. Fuel and oxidizer reaction channels are directly over alternating cathode electrode catalyst structure current extractors **350**, **360** and anode electrode catalyst structure current extractors **355**. These alternating anode and cathode electrode catalyst structure current extractors serve as connections to a load through the anode and cathode metallic conductor structures and can be series or parallel interconnected depending on current or voltage levels of output power required.

(Currently Amended) [0053] While a simplified sectional view of the disclosed fuel cell ~~element~~ electrode assembly is shown in FIG. 2. A more detailed description is disclosed for one specific embodiment in FIG. 4 through FIG. 10. Accordingly the specific processes described ~~is~~ are ~~one~~ an example of a variety of materials and fabrication techniques that are well known in microfabrication art and can be used for fabrication of the ~~structure~~ fuel cell electrode assembly.

(Currently Amended) [0054] Referring to FIG. 4a a starting single monolithic substrate **410** may be of metal, semiconductor or insulator. Copper, silicon or glass respectively are examples of the substrate materials possible. If silicon or any conducting monolithic substrate is chosen, FIG 4b, then a first layer of silicon nitride **415,** for example, is deposited to insulate the next anode and cathode metallic structure current extractor lines **435** from monolithic substrate **410**. The insulator layer can be applied by Physical Vapor Deposition (PVD) or by Chemical Vapor Deposition (CVD) for example. Next in FIG. 4c an adhesion layer **420** and a preplate layer **425** is deposited on top of insulator layer **415** by PVD or CVD means. These materials may typically be chromium and copper respectively. In FIG. 4d a masking layer of photosensitive resist **430** is applied to the ~~wafer~~ substrate at a thickness somewhat greater than the thickness of layer **435** to be plated. The resist mask is patterned by lithographic conventional means to expose those areas that will become the anode and cathode metallic conductor structure current extractor ~~conductors~~ lines **435**. Next in FIG. 4e the anode and cathode metallic conductor structure current conductor lines are plated up typically in a copper or nickel plating bath. Plated thickness of the lines meet the requirement for minimum voltage drop for extracted current and may be additionally used to conduct heat away from the ~~proton~~ ion exchange membrane. In FIG. 4f the resist mask **430** is stripped by conventional means leaving copper current extractor lines on the preplate bus layers **420** and **425**. Next in FIG. 4g copper **425** and chromium **420** layers are etch removed using the much thicker plated copper layer **430** as a mask. Some of the plated copper will also be removed.

(Currently Amended) [0055] The fabrication process is continued in FIG. 5a. Monolithic substrate **410** with insulator layer **415**, adhesion layer **420**, preplate layer **425** and plated anode and cathode metallic conductor structures **435** are disposed as in FIG. 4g. ~~wherein~~ A barrier layer **440**, if required, is applied typically by PVD or CVD conformably over the anode and cathode metallic conductor structure current collector lines **435** and the space between. This material is typically a refractory conductor such as tantalum nitride or titanium/tungsten/nitride alloy but may be more specifically determined by the nature of the corrosion expected between the electrode and the ~~proton~~ ion exchange membrane material with the fuel and oxidizer used. In FIG.5b a photomasking step using resist **445** is performed to etch away the barrier material between the anode and cathode metallic conductor structure current extractor ~~electrodes~~ lines in order to avoid electrical shorts between adjacent **435** lines. In FIG. 5c ~~the~~ barrier layer **440** is etched using either wet etching or dry etching technology common in the microfabrication industry. In FIG. 5d the resist mask **445** is stripped. Next a solution of membrane material **450** is spin coated over the surface of the substrate to a thickness significantly greater than the height of anode and cathode metallic conductor current carrying lines **435**. This material may be Nafion or other ~~proton~~ **ion** exchange membrane material that is in solution form. Application may also be from Chemical Vapor Deposition using an ion exchange membrane precursor. Other ion exchange membrane application techniques are dipping and doctor blading for example. After ion exchange membrane material **450** deposition the ion exchange membrane is heat cured to drive off excess solvent.

(Currently Amended) [0056] Fig. 6 continues the fabrication process. ~~wherein~~ Monolithic substrate **410** with insulator layer **415**, adhesion layer **420**, preplate layer **425**, plated anode and cathode metallic conductor structures **435**, barrier layer **440** and ion exchange membrane layer **450** are disposed as in FIG. 5e. FIG. 6a represents the cured ~~proton~~ ion exchange membrane material **450**. Fig 6b shows a photomasking pattern **455** required for anisotropically etching the ion exchange membrane material down to barrier layer **440**. FIG. 6c illustrates the anisotropic shape of the membrane sidewalls after etching using ~~a~~ resist mask **455** to define channels in the ion exchange

membrane. Such anisotropic etching is accomplished using a Deep Reactive Ion Etching (DRIE) technique common in MEMS fabrication technology. A reactive gas such as a combination of O2, SF6 or CH3 in conjunction with He as a cooling gas is employed in a low pressure plasma system. In FIG. 6d the resist mask **455** is stripped in a conventional stripper solution. As an option at this point in the process, FIG 6e, a thin layer of porous catalyst **460**, ~~FIG 6e~~ may be deposited over the surface of exposed structures to catalyze the fuel cell reaction at the interface between the ~~proton~~ ion exchange membrane and the anode and cathode electrode catalyst structure material. The catalyst is deposited by PVD or CVD technique. The material ~~can~~ may be a Pt/Rb or other novel layer in the case of a Polymer Electrolyte Membrane Fuel Cell (PEMFC) or zirconia based electrolyte layer in the case of a Solid Oxide Fuel Cell SOFC.

(Currently Amended) [0057] Referring now to FIG. 7. Monolithic substrate **410** with insulator layer **415**, adhesion layer **420**, preplate layer **425**, plated anode and cathode metallic conductor structures **435**, barrier layer **440**, ion exchange membrane layer **450** and barrier layer **460** are disposed as in FIG. 6e The fabrication process continues with FIG. 7a wherein a layer of anode and cathode electrode catalyst structure material **465** in the form of a slurry or thick liquid is applied by spin coating, dipping or doctor blading technique commonly found in the microfabrication industry. For PEMFC type fuel cells a heavy suspension of carbon in a carrier is utilized, for example, and in SOFC this may be a yttria stabilized zirconia material dispersed in a heavy solution, for example. The catalyst associated with the anode and cathode electrode structure may be embedded within the structure or take the form of a surface deposited layer **460**. After deposition ~~this~~ the anode and cathode electrode catalyst layer is heat cured at the appropriate temperature wherin it becomes densified. Next the anode and cathode electrode catalyst structure is polished/planarized as shown in FIG. 7b so as to expose both ion exchange membrane **450** and anode and cathode electrode catalyst structure material **465** as a planar surface. At the same time the thin layer of surface catalyst **460**, if present, is removed from the top surface of the ion exchange membrane **450**. The polish/planarization technique is commonly used in the semiconductor industry for planarization of on chip copper interconnect which is embedded in low K dielectric

material and is similar to PEMFC material discussed herein. After adequate post polish surface cleaning an insulating layer **470** of silicon nitride or silicon dioxide is deposited by PVD or CVD the purpose being to electrically isolate fuel and oxidizer channel separator walls FIG. 8b, **485** from the anode and cathode electrode catalyst structure material. In FIG. 7c insulating layer **470** is followed by deposition of adhesion layer and preplate layer **475** of chromium and copper respectively, for example, using PVD or CVD technique. Adhesion and preplate layers **470** are shown as one layer for simplicity. Finally a photomasking layer **480**, FIG. 7d, is applied to the surface of the copper preplate layer and chrome adhesion layer **475** photolithographically patterned~~, FIG. 7d,~~ to expose the area of preplate copper that will form (when plated up) the walls of the fuel and oxidizer channel~~s~~ structures.

(Currently Amended) [0058] Now referring to FIG. 8a. Monolithic substrate **410** with insulator layer **415**, adhesion layer **420**, preplate layer **425**, plated anode and cathode metallic conductor structures **435**, barrier layer **440**, ion exchange membrane layer **450** and barrier layer **460**, anode and cathode electrode catalyst structures **465**, insulating layer **470**, adhesion and preplate layer **475** and resist layer **480** are disposed as in FIG. 7d. Next copper or nickel region **485**, the lower portion of the channel cover plate structures, is plated up so as to form fuel and oxidizer channel structure walls of height generally slightly less than the thickness of the resist mask. Following fuel and oxidizer channel wall plateup the masking layer **480** is stripped, FIG. 8b, by conventional means leaving channel openings **490**, FIG. 8c, between the fuel and oxidizer channel walls. Next as shown in FIG. 8c layers 475 preplate layer and adhesion layer are etched away using the thick fuel and oxidizer channel structure wall layer as an etch mask. Some minor etching of the wall layer will occur. Notice the widths of **485** and **490** are not shown to scale, **485** normally being narrower than **490**. Layers **475** are wet or dry etched by techniques common in the microfabrication industry. Finally in FIG. 8c insulating layer **470** is etched using the remaining layers **475** and **485** as an etch mask. Removal of layer **470** is accomplished by either wet or dry plasma etch technique, again a process common in the microfabrication industry. FIG. 8c completes the basic fuel cell structure which includes anode and cathode metallic conductor current extractor ~~leads~~

lines **435**, ~~proton~~ ion exchange membrane **450**, anode and cathode electrode catalyst structures ~~with catalyst~~ **465**, optional thin catalyst layer **460**, ~~and~~ fuel and oxidizer channels **490** and fuel and oxidizer channel structure walls 485 all fabricated on ~~the single~~ one side of a planar single monolithic substrate. Fabrication of a top channel cover plate structure integral with the basic fuel cell electrode assembly ~~cell~~ completed previously as shown in preceding drawing figures 4, 5, 6, 7, and 8 continues specifically as illustrated in FIGS. 10, 11, 12, and 13 that follow.

(Currently Amended) [0059] Reference to FIG. 9 will illustrate the strategy for forming ~~an integral top~~ channel cover plate structures containing vias and channels for removal of excess fuel and oxidizer from the active part of the cell. FIG. 9a shows a top view of a much reduced in complexity fuel cell electrode assembly channel cover plate **600**. Illustrated are four square large fuel and oxidizer manifold supply and exhaust structure manifold chambers **615**, **620**, **625** and **630** that are opened up through all deposited layers used to form the fuel cell electrode assembly. At the end of the process the substrate material is also removed in these areas to allow stacking of the individual ~~micro~~ fuel cell~~s~~ electrode assemblies as shown in FIG. 14a. ~~Manifold~~ Structure **625** feeds oxidizer (oxygen for example) into the comb structure channels **650** formed by layers 605 and 485, FIG. 9b, which are formed as a last step in FIG. 8c, **490**. Oxidizer flows up through vias **640** ~~to be~~ which is formed in the lower channel cover plate structure and thence out through channel **655** (bold outline) to oxidizer output structure ~~manifold~~ **620**. The flow path is mirrored through a complimentary network of channels in the channel cover plate structures ~~cover~~ for the fuel. Input ~~manifold~~ structure **630** supplies fuel (hydrogen for example) to ~~comb~~ channel~~s~~ **cover plate structure 645** then through vias **635** and out to fuel output ~~manifold~~ structure **615**. The strategy is made more apparent through the examination of sections A-A and B-B as shown in FIGS. 9b and 9c where only the base anode and cathode electrode catalyst structures ~~terminals~~ **465** are shown for simplicity. The integral channel cover plate structure ~~cover~~ consists of three thick plated metallic layers. A first layer **485** represents the final layer **485** of FIG. 8c and forms fuel and oxidizer channels fabricated previously in the fuel and oxidizer channel structure layer. A second **605** layer seals fuel and oxidizer channels

490 (fabricated at FIG. 8c) while supplying via holes **635** and **640** for passage of fuel and oxidizer into exit channels **650** and **655**. A third layer **610** forms exit channels **650** and **655** in FIG. 9a to ~~manifolds~~ structure **615.** ~~and 620. respectively.~~ Layers **485**, **605** and **610** are formed by conventional photomasking and plating. The detailed fabrication sequence for the channel cover plate structures is illustrated in FIGS. 10, 11, 12 and 13.

(Currently Amended) [0060] The preferred embodiment of the integral channel cover plate structures fabrication begins as shown in FIG. 10a where a photomasking layer **705** is applied to the surface of the previously fabricated structures **435**, **450**, **465** and **485**. For simplicity only the salient upper layers of the base fuel cell electrode assembly structure are shown in FIG. 10. Fuel and oxidizer channel structure walls **485** and anode and cathode electrode catalyst structure material **465** are exposed at the top surface of the starting structure. Fig. 10b illustrates the masking layer patterned to expose the metallic fuel and oxidizer channel structure walls **485**. Next an adhesion layer and preplate layer **710** is deposited over masking layer **705** and on the surface of fuel and oxidizer channel structure wall ~~structure~~ **485**. Typically these layers will be titanium and copper or nickel respectively and are deposited by vacuum evaporation on a cooled substrate if necessary, for example. Referring to FIG. 10d another masking layer **720** is applied to the surface of previously deposited layers **710** and the masking layer is patterned photolithographically to form via structures **715** (**635** and **640** in FIG. 9a) in resist over the buried anode and cathode electrode catalyst structure layers. Finally in FIG. 10e a ~~plateup~~ metal layer of copper or nickel **735,** for example, is applied by well known plating techniques.

(Currently Amended) [0061] Channel cover plate structure fabrication process continues as exemplified in FIG. 11. Previously fabricated layers **435**, **465**, **450**, **485**, **710** and **735** are shown for reference. The photomasking material **720** of FIG. 10e is stripped from the ~~substrate~~ surface of layers **710** leaving the exposed plated layer **735** with adhesion and preplate layer **710** between. Next, in FIG. 11b adhesion and preplate layer **710** is etched using, typically, wet chemistry leaving previously deposited resist layer **705** exposed at the top surface. Future via spaces **740** are also exposed over resist layer

705. Another photomasking layer **760** is applied in FIG. 11c and photolithographically exposed and developed to expose previously plated area **735**. Note that **735** and **750** are part of the same plated layer while space **755** will become plated further along in the process. Finally, FIG. 11d, another adhesion and preplate film **765** is deposited by vacuum evaporation onto photomasking region **760** and the previously plated copper or nickel layer **735** for example. While not intuitively obvious from FIG. 11d a substantial amount of layers **765** are in contact with previously plated layer **735** thus by suitable mask design typically more than half of layer **765** is supported by plated layer.

(Currently Amended) [0062] Fig. 12a adds another layer of photomask **775** to adhesion and preplate layer **765** and defines plateup area **770** of the second metal layer of the channel cover plate structure top layer **780**. Previous layers **450**, **705**,**465**, **435**, **745**, **735**, **760** and **765** are shown for reference purposes. FIG. 12b shows the plated ~~up~~ layer **780**, the last metal layer of the channel cover plate ~~cover~~ structure. Finally the photomask is removed from area **785** of FIG. 12c by conventional resist stripping means using an organic solvent.

(Currently Amended) [0063] Final processes for channel cover plate structure fabrication are shown in FIG. 13. Previously fabricated layers **435**, **465**, **450**, **485**, **710**, **760**, **765** and **735** are shown for reference. Fig. 13b indicates removal of exposed preplate and adhesion layer **765** using the plated copper or nickel thick film **780** as a mask. Removal is accomplished by wet etching. As a final step in cover fabrication buried layers of photomask material **705** and **760** left over as temporary support for enabling via and channel fabrication in the channel cover plate structure are removed through slow dissolution in hot solvent stripper such as an NMP commercial based stripper. Since some of the photomask is buried in small channels the dissolution solvent is stirred and ultrasonic agitation is used over a period of ~~several~~ a few hours. The completed fuel cell electrode assembly ~~element~~ is shown in FIG. 2 in cross section and has been fully fabricated by sequential processing on a planar single monolithic substrate. Such a series of process steps are highly amenable to a semiconductor manufacturing facility.

(Currently Amended) [0064] To complete the fuel cell electrode assembly ~~element~~ fabrication of the channel cover plate structure side of the fuel cell electrode assembly array is photomasked and the fuel and oxidizer manifold supply and exhaust structure ~~channels~~ cavities are opened in ~~the~~ a resist mask exposing the single monolithic substrate surface. The back side of the single monolithic substrate may be masked with a blanket unpatterned masking layer, if necessary, to avoid backside etching during manifold channel etching. The substrate is then either wet or dry etched completely through from the structure side rendering four ~~channels~~ cavities through a unit fuel cell electrode assembly ~~element~~ as shown in FIG. 2, **260**, **265**, **270** and **275**. Finally the ~~structure~~ fuel cell electrode assembly is stripped of masking material to provide for an array of elemental ~~micro~~ fuel cell~~s~~ electrode assemblies that can be singulated by standard semiconductor sawing or laser scribing technology, for example.

(Currently Amended) [0065] Prior to etching the fuel and oxidizer manifold supply and exhaust structure through ~~channels~~ cavities the single monolithic substrate may be thinned by lapping and polishing in order to reduce the stacking dimensions of an array of stacked fuel cell~~s~~ electrode assemblies such as that shown in FIG. 14. An individual fuel cell may be as thin as 0.25 mm by virtue of lap thinning, for example. Thus a stack of 20 to 30 fuel cell ~~elements~~ electrode assemblies per cm. of stacking height is feasible while allowing for a thin layer of stacking adhesive between each individual cell. Hermetic sealing between elemental fuel cell~~s~~ electrode assemblies is accomplished by soldering, brazing, adhesive or epoxy bonding depending on the operating temperature of the fuel cell electrode assembly stack. Such hermetic sealing techniques are well known in semiconductor Back End Of the Line (BEOL) technology.

(Currently Amended) [0066] FIG. 14a illustrates a stack of four reduced complexity fuel cell electrode assemblies **800** ~~elements~~ with part of the front sectioned to show functionality.
Partial detail of each individual fuel cell electrode assembly is shown in order to simplify the stack drawing. For reference **825** is the ion exchange membrane material, 830 is the

anode and cathode electrode catalyst structure material, **835** is the anode and cathode metallic conductor material,**845** represents, in different cross hatching all the layers of the channel cover plate structure built up with solid metal, **850** is the single monolithic substrate, **855** is the top channel in the channel cover plate structure, **860** is the fuel channel formed between fuel and oxidizer channel separator walls **485** FIG. 8c, **865** is a via in the fuel channel of the channel cover plate structure and **870** is the oxidizer channel formed by the bottom layer of the channel cover plate structure.

The elemental fuel cell~~s~~ electrode assemblies are sealed together with a layer **840** of solder, braze or adhesive, for example. The fuel and oxidizer manifold supply and exhaust ~~channels~~ cavities **805**, **810**, **815** and **820** are aligned such that the cavities are propagated through the entire body of the fuel cell electrode assembly stack providing means for fuel and oxidizer access to each stacked fuel cell electrode assembly. ~~element.~~ Such arrangement allows tubulations to be attached to the top face of the stack by conventional means such as soldering, brazing, epoxy seal or adhesive seal. The bottom end of the fuel cell electrode assembly stack may also be provided with tubulations for connection to balance of plant if required or can be blanked off using a solid plate.

(Currently Amended) [0067] Fig. 14b stack **900** illustrates a method of stacking individual fuel cell electrode assemblies ~~elements~~ such that anode and cathode metallic conductor structure current extraction leads **210** and **215** of FIG. 2 are exposed at the edge of the stack for connection to an external load. **910** represents an edge of a metallic conductor structure for such connection. **915** is a single monolithic substrate, **920** represents the full fuel cell electrode assembly sequentially built up on single monolithic substrate **915 and 905** is the adhesive layer bonding each of the fuel cell electrode assemblies to each other.

(Original) [0068] Current state of the art in PEMFC technology indicates an average power available per square cm. of cell surface to be about 0.5 watts/cm. sq. of active membrane. Typical output values of 1 amp at 500mV are achievable. Thus a stack of 30 thinned substrate fuel cell elements as described in this disclosure where each

element is of a size to yield about a 1 sq. cm. of reaction area can provide 15 watts of power running efficiently on hydrogen and air.

[0069] While specific embodiments of the described invention have been disclosed along with a preferred method of manufacture the invention may be fabricated with other materials and processes that are known in the microfabrication art and the disclosed materials and processes are not intended to be limiting. Process and materials modification will become apparent to those skilled in the art.

(New) [0070] This invention claims a process for forming a fuel cell electrode assembly through sequential fabrication steps on a single side of a single monolithic substrate thereby making use of a continuous manufacturing process for speed of fabrication and cost reduction.

(New) [0071] This invention also claims a process which enables the fabrication of anode and cathode electrode catalyst structures and ion exchange membrane structures which are thicker than the ion exchange membrane is wide thus increasing the area of active ion exchange compared to the conventional planar cell. Ion exchange takes place in a direction parallel to the substrate surface.